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Updated Cost Savings Estimate with Uncertainty for Enhanced Sludge Washing of Underground Storage Tank Waste at Hanford

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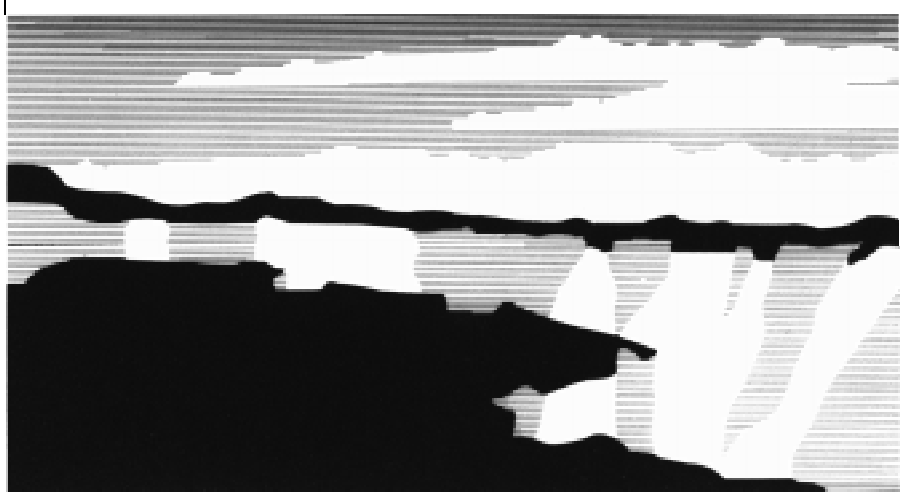

Los Alamos
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Abstract

Past Enhanced Sludge Washing (ESW) cost saving studies have been updated based on the "Independent Review of Hanford High Level Waste Volume" and most recent "Tank Waste Remediation System Operation and Utilization Plan". By way of the update, it has been estimated that implementation of ESW in the Tank Waste Remediation System (TWRS) at the Hanford site can save approximately $4.8B over the use of a simpler water wash. The simpler water wash dissolution was defined as achieving 85% that of ESW dissolution. It was further estimated that based on the water wash comparison, the $4.8B savings was uncertain within ± $1.6B at the 95% confidence interval. While some confusion has arisen due to the fact that ESW has already been included in the TWRS remediation baseline at Hanford, and hence an additional Site cost savings cannot be realized, the ESW cost savings is reported here to take credit for the ~$30M invested in ESW technology development.

Introduction

There exists approximately 100 million gallons of radioactive waste in underground storage tanks (USTs) at Department of Energy (DOE) sites across the United States. Approximately 54 million gallons are stored at the Hanford site. The DOE is responsible for immobilization and permanent disposal of this tank waste. The Hanford tank waste is currently classified as high-level waste (HLW). While low-level waste (LLW) can generally be disposed of subsurface on-site, HLW must be disposed of in an underground repository such as that planned for Yucca Mountain. Since LLW disposal is obviously much less expensive than HLW, the plan for remediation at Hanford is to separate the UST waste into a small volume of HLW and large volume of LLW.

Of the 54 million gallons of UST waste at Hanford, approximately 20 vol-% is solids-based consisting primarily of sludge, and the remaining 80 vol-% is liquid-based consisting of supernate, salt cake, and slurry liquid as shown in Figure 1. The sludge consists of well over 99 wt-% non-radionuclides as indicated by Figure 2. Without some type of sludge processing, the non-radionuclides will dictate a very large volume of immobilized HLW for permanent disposal. Therefore, partial separation of some non-radionuclides from the sludge, such as aluminum, chromium, sodium, and phosphorus, with a caustic wash referred to as Enhanced Sludge Washing (ESW) is an essential step in reducing the final amount of HLW to be disposed of in the underground repository. Even with ESW, radionuclide loading in the final immobilized HLW will be approximately fifty-times less than that permitted by radionuclide heat generation alone [Swanson, 1994, pg. 155]. This is because the non-radionuclides can dictate the

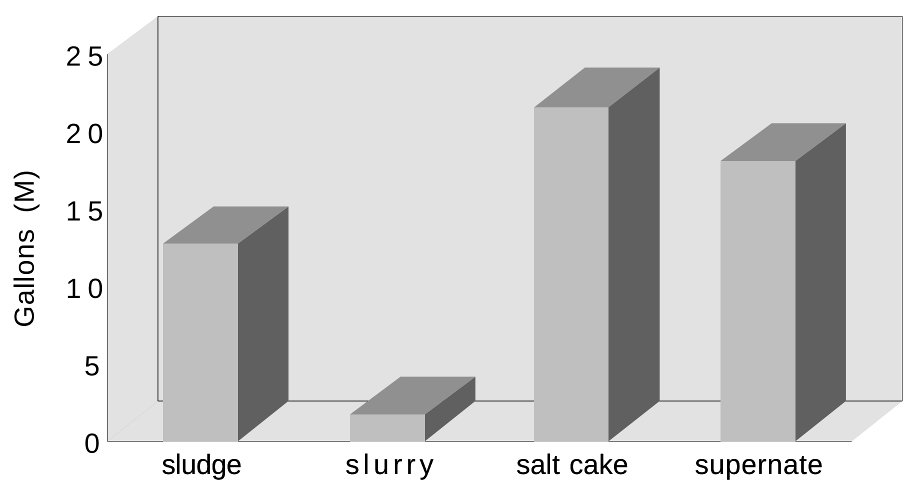

Figure 1. Hanford UST waste type

final immobilized glass volume, due to physical property limitations such as the rate of glass crystallization. The aluminum, chromium, sodium, and phosphorus separated from sludge can then be disposed of as LLW. Consequently, processing which significantly reduces the non-radionuclide concentration in the sludge can have a very large impact on the overall remediation cost.

Sludge wash testing has been primarily funded by the Department of Energy's Office of Science and Technology (OST). Since each of the 177 USTs at Hanford has a unique waste composition, no single set of sludge wash process conditions will minimize the final amount of immobilized HLW. The sludge wash process being developed at Hanford is referred to as enhanced sludge washing indicating development beyond a generic process for all waste. Process parameters being evaluated and/or optimized include time, temperature, caustic (NaOH) concentration, and additives targeting dissolution of specific species such as chromium. The time and temperature affect both the capital and operating costs. Excess caustic can produce excess LLW, and produce excess radionuclide dissolution that can increase the processing complexity of the dissolved sludge solution.

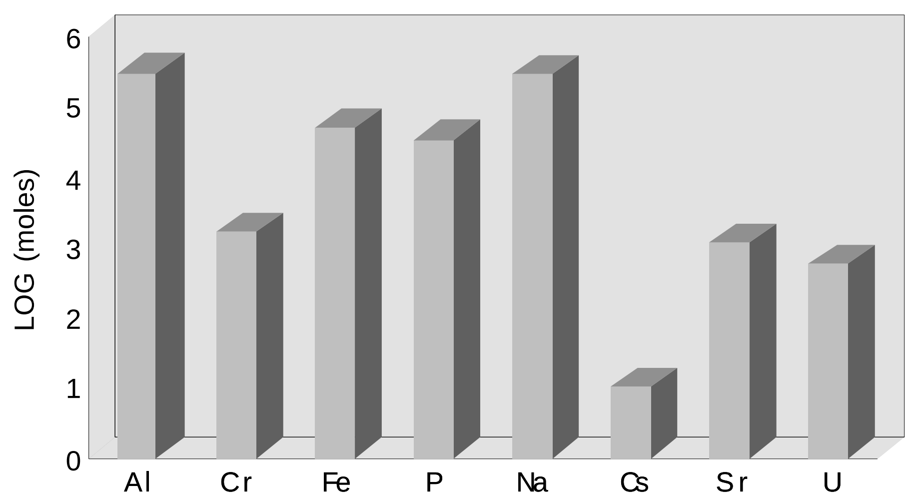

Figure 2. Sludge composition

Three past ESW cost studies have been conducted by the author. The first study [DeMuth, March 1997] was based upon the original Westinghouse Tank Waste Remediation System (TWRS) flowsheet, which included the ESW separation factors of 1995 [Orme, et al., August 1995]. The second study [DeMuth and Williams, October 1997] was a revised version of the first, based upon the initial Westinghouse Privatization flowsheet, which included the ESW separation factors of 1996 [Orme, et al., September 1996]. The third study [DeMuth and Shieh, 1999] was a revised version of the second, based upon the initial TWRS Operation and Utilization Plan, which included Colton's 1997 ESW separation factors [Kirkbride, et al., September 1997]. The first study determined the potential ESW cost savings at Hanford to be $8.7 B, the second study determined the potential ESW cost savings to be $6.3 B, and the third study determined the potential ESW cost savings to be $4.8 B $\pm$ $0.7 B at the 95% confidence interval.

This effort is the latest revision in the author's series of ESW cost studies, and is based upon the revised TWRS Operation and Utilization Plan which included ESW separation factors more dependent on the waste and tank type then previous studies [Kirkbride, et al., May 1999], and the Independent Review of Hanford High Level Waste Volume [Plodinec, et al., April 1996]. In particular, waste blending factors are included so that the HLW glass volumes match those of the "Independent Review of Hanford High Level Waste Volume".

Methodology

The methodology used to estimate the cost savings and associated uncertainty is shown in Figure 3. A process model based on material balances was prepared by simplifying existing Site flow sheets [Orme, et al., 1995 & 1996, and Kirkbride, et al., 1997 & 1999]. The R&D, capital and operating cost for each unit operation of Figure 4 is shown in Table 1 in 1995 dollars, and were gathered primarily from the TWRS EIS [Slaathaug, 1995]. Uncertainties in the process and cost parameters were estimated by engineering judgement and modeled as triangular distributions. The process and cost parameter uncertainties were propagated to the overall remediation cost as events of equal probability similar to a formal Analysis of Variance (ANOVA) [Anderson and McLean, 1974]. The set of discrete remediation costs were then converted to a normal distribution, and the uncertainty in the difference between the ESW and non-ESW remediation cost was then estimated by way of a "two-sample t-test" [Afifi and Azen, 1979].

The process model parameter of primary interest for this study has been the distribution of liquid versus solid species following the ESW unit operation. The other process parameters shown in Figure 4, such as the distribution of liquid versus solid following tank retrieval and the distribution of radionuclides following the radionuclides separation, essentially remained unchanged and fixed by the Site flow sheet [Kirkbride, et al., 1999]. The final low-level and high-level waste glass volumes were estimated in a fashion similar to the Site flow sheets [Orme, et al., 1995 & 1996, and Kirkbride, et al., 1997 & 1999]. The ESW separation factors were chosen as weighted global values representing all of the waste types, as determined from the material balances of the most recent Site flow sheet [Kirkbride, et al., 1999]. The sludge separation factors for the non-ESW case, with which the ESW case was compared for the cost savings, was assumed to be 85% of the ESW separation factors.

The unit operation costs were collected primarily from the original Tank Waste Remediation System (TWRS) EIS from 1995. While much knowledge has been gained since 1995 which could bring into question the use of four year old data, cost studies since that time have been related to the Privatization effort with its associated proprietary issues. Therefore, the 1995 EIS is probably still the best single integrated TWRS cost estimation available to the public. The costs in this study were determined by adjusting the TWRS EIS costs in accordance with the associated change in throughput for the unit operation of interest, and inflated by a 3.5%/yr discount factor for current day dollars. As an example, if the ESW unit operation for the TWRS EIS was based on 20,000 MT-solids, and the throughput for this study was 30,000 MT-solids, the ESW unit operation capital and operating cost for this study would be 50% greater than the TWRS EIS.

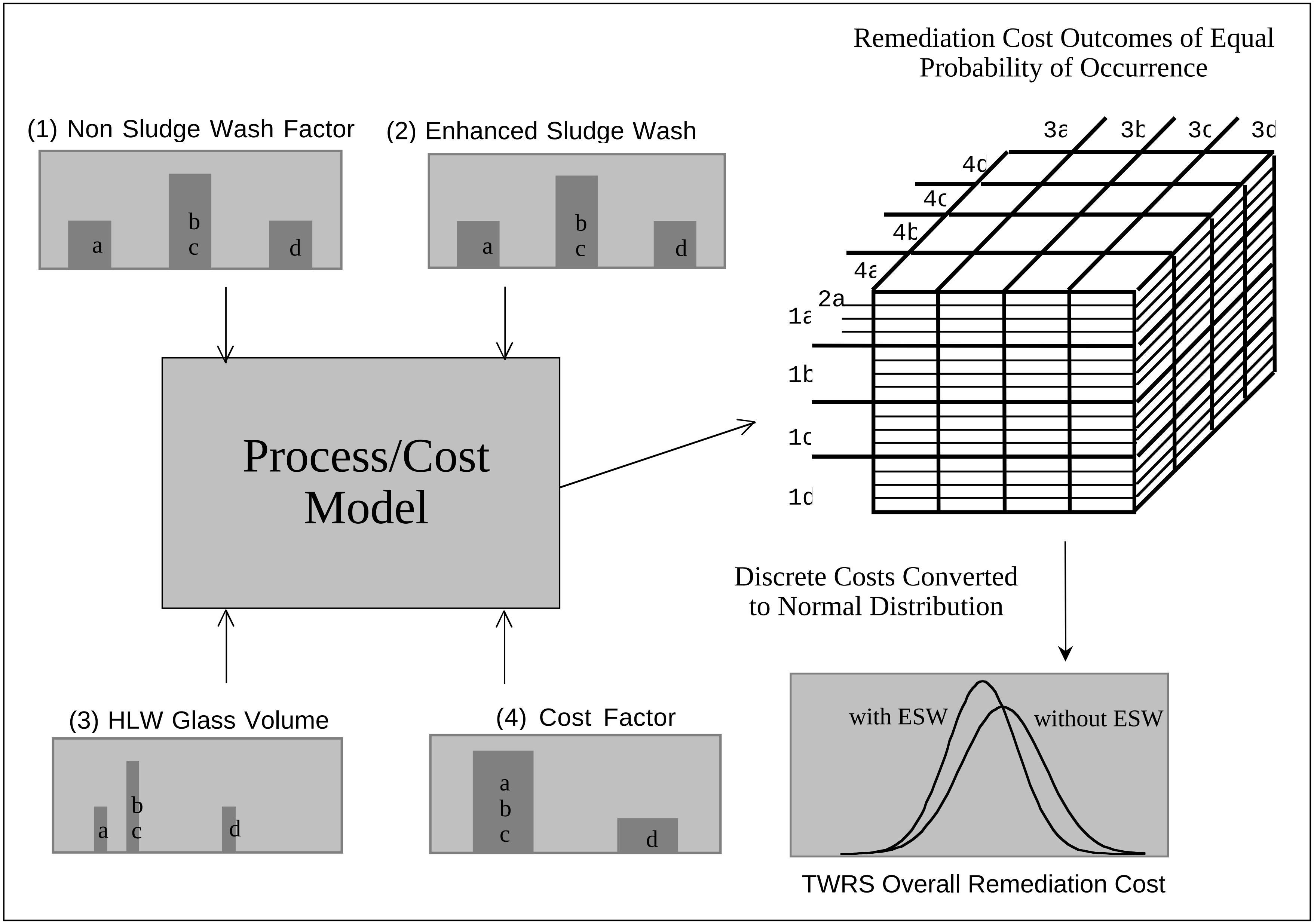

Figure 3. Uncertainty Methodology

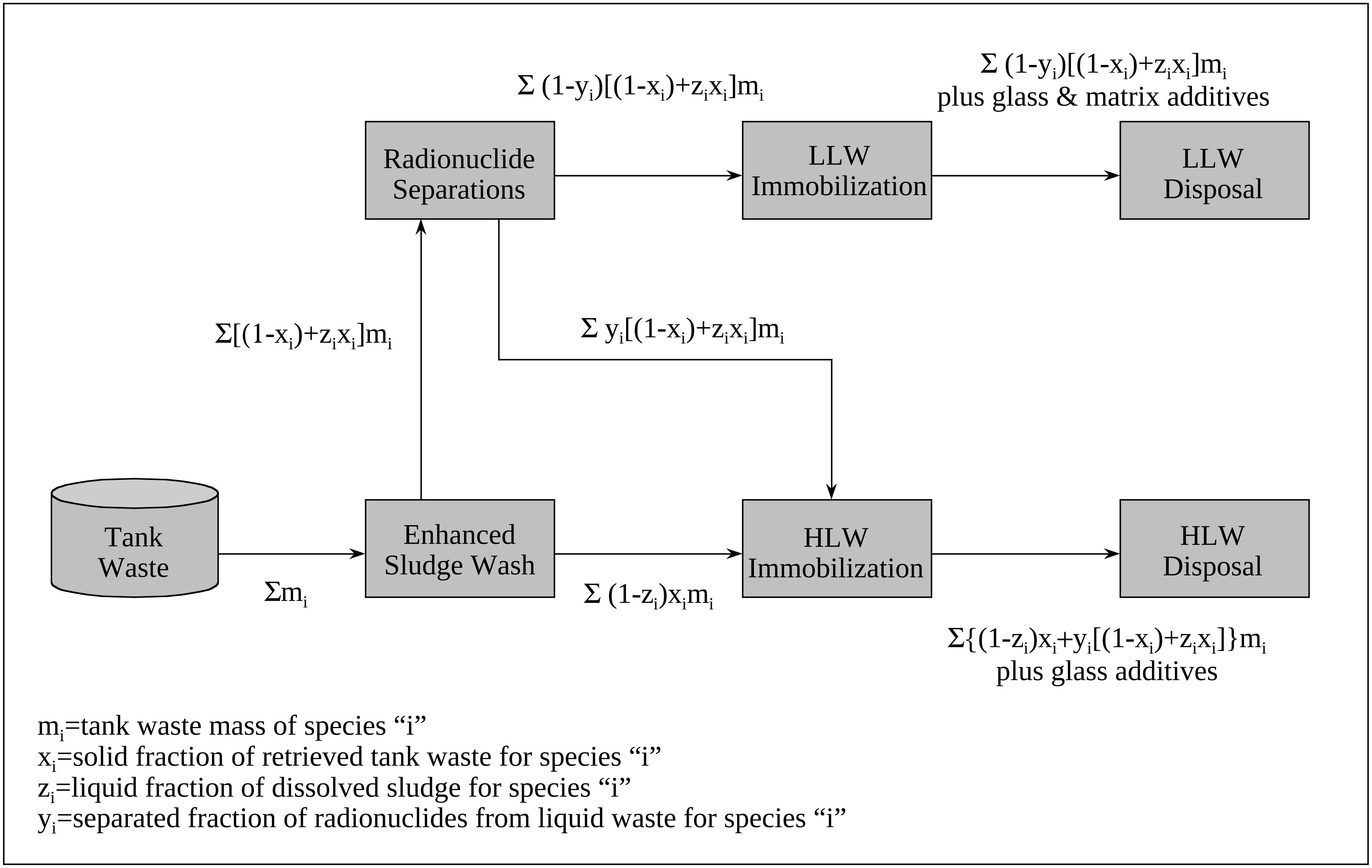

Figure 4. Process Model

	Capital ($M)	Operating ($M)	R&D ($M)	Total ($M)
Retrieval[a]	5100	3700		8800
Liquid Separations[b]	792	276	83	1151
Sludge Wash[b]	69	129	9	207
LLW Immobilization[b]	2228	624	264	3116
LLW Disposal[b]	264	16	14	294
HLW Immobilization[b]	2231	639	260	3130
HLW Disposal[b]	5858	31		5889
Total				22,587

[a]Tri-Party Agreement, Case Beta

[b] E.J. Slaathaug, TWRS EIS, Table F-36

Table 1. TWRS EIS Unit Operation Costs in 1995 dollars

The triangular distributions of Figures 5 though 8 were estimated by engineering judgment. The non-ESW sludge separation factor of 85% that of ESW was assumed to range from approximately 70% to 100%, with a linear probability distribution. Therefore, if 70% and 100% had approximately a zero probability of occurrence, and 85% had the maximum probability of occurrence, half the distance from 70% to 85% and 85% to 100% should have half the probability of occurrence as 85%. Similarly, uncertainty in the ESW separation factor was assumed to be ± 20% of the mean value; therefore, ±10% of the mean value had one half the probability of occurrence as the mean value itself. However, the unit operation cost uncertainty was not assumed to be symmetrical because it was thought unlikely that the actual costs would be less than the TWRS EIS values. Rarely do cost estimates decrease with project maturity, and in fact they usually increase. Therefore, it was assumed the TWRS EIS costs (accounting for inflation) would have three times the probability of occurrence as costs 20% greater. And finally, the high-level waste (HLW) glass volume was assumed to range from 13,800 to 50,000 canisters with a median value of 23,000 canisters. This distribution was also non-symmetrical with a linear probability function. Consequently, if the probability of occurrence of 13,800 and 50,000 canisters was approximately zero, then 18,400 and 36,500 canisters had one half the probability of occurrence as the median value 23,000 canisters. Based upon the process model of this study and the most recent Site flow sheet, it was determined a blending factor slightly greater than two (or ~50% blending efficiency) would yield 23,000 HLW canisters.

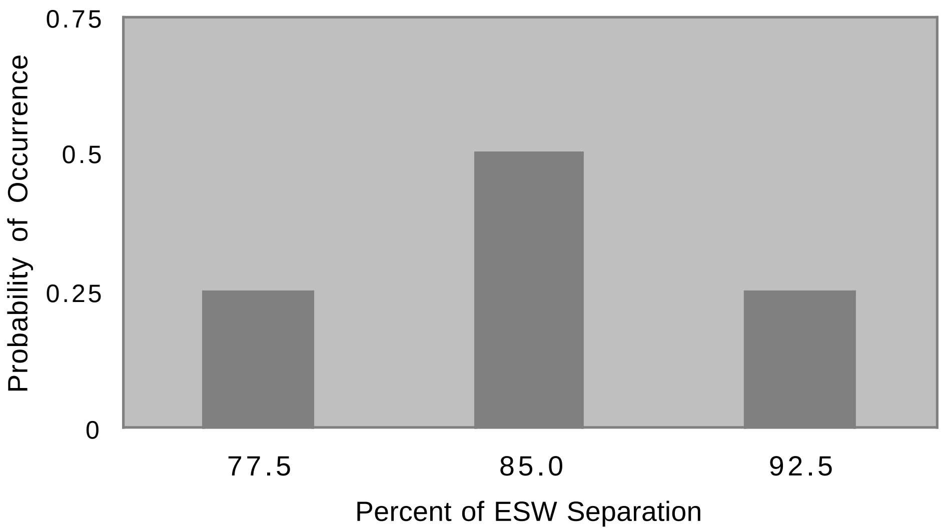

Figure 5. Non-ESW Uncertainty

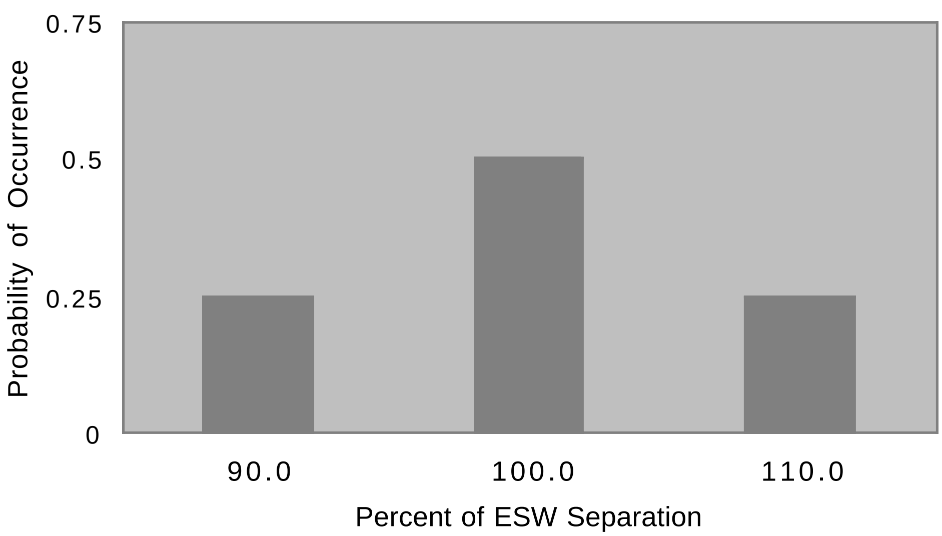

Figure 6. ESW Factor Uncertainty

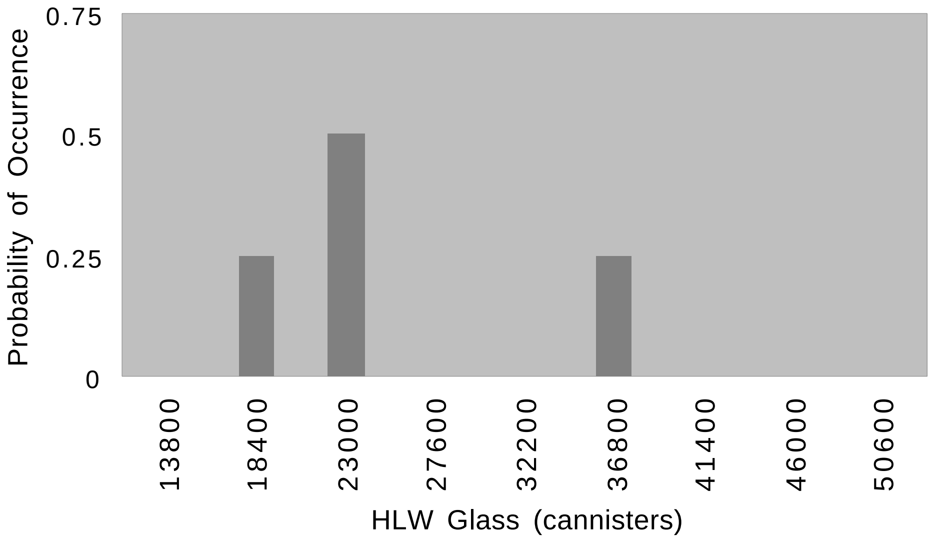

Figure 7. HLW Glass Volume Uncertainty

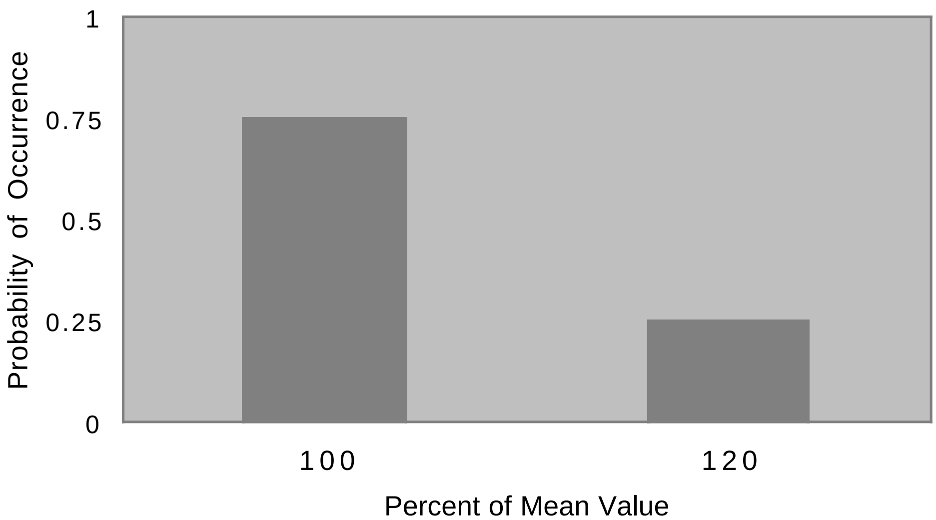

Figure 8. TWRS EIS Remediation Cost Uncertainty

The process and cost parameter uncertainties shown in Figures 5 through 8 were selected to each provide four outcomes of equal probability for the analysis of variance. Each cell in the cubic matrix of Figure 3 represents a remediation cost event of equal probability. The discrete set of remediation costs represented by the cubic matrix can then be transformed to a continuous probability function such as a normal distribution. As shown in Figure 3, it is then possible to represent the affect of the process and cost parameter uncertainties, upon the overall TWRS remediation cost for non-ESW and ESW, as normal distributions. A "two sample t-test" can then be used to estimate the uncertainty for the difference between the mean values of the normal distributions as shown by the following. The difference between the mean values of the normal distributions is the cost savings due to the use of ESW.

$$\left(\mu_{\mathrm{nonESW}} - \mu_{\mathrm{ESW}}\right) \pm t_{1-(\alpha/2)}\left(n_{\mathrm{nonESW}} + n_{\mathrm{ESW}} - 2\right)\sigma_{p}\sqrt{\frac{1}{n_{\mathrm{nonESW}}} + \frac{1}{n_{\mathrm{ESW}}}}$$

$$\sigma_{p}^{2} = \frac{\left(n_{\mathrm{nonESW}} - 1\right)\sigma_{\mathrm{nonESW}}^{2} + \left(n_{\mathrm{ESW}} - 1\right)\sigma_{\mathrm{ESW}}^{2}}{\left(n_{\mathrm{nonESW}} + n_{\mathrm{ESW}} - 2\right)}$$

μ = mean

σ = standard deviation

n = degrees of freedom (number of occurrences)

t = t - statistic

α = confidence interval

If we wish to estimate the uncertainty at the 95% confidence interval, the t-statistic is approximately two [Afifi and Azen, 1979].

$$\alpha = 0.05$$

$$t_{1-(\alpha/2)} \approx 2$$

$$\left(\mu_{\mathrm{nonESW}} - \mu_{\mathrm{ESW}}\right) \approx 1020\sqrt{\frac{1}{128}\left(\frac{255}{510}\right)\left(\sigma_{\mathrm{nonESW}}^{2} + \sigma_{\mathrm{ESW}}^{2}\right)}$$

$$n_{\mathrm{nonESW}} = n_{\mathrm{ESW}} = 4^{4} = 256$$

Results & Conclusions

Figures 9 and 10 show the overall TWRS remediation cost and HLW glass volume distributed discretely, based on the 256 scenarios represented by the cubic matrix of Figure 3. Figures 11 and 12 were created by a normal distribution curve fit to the data of Figures 9 and 10 respectively. A normal distribution was selected to represent the data of Figure 9, because it provided a means to estimate the uncertainty between the nonESW and ESW remediation cost, i.e. the ESW cost savings uncertainty. The uncertainty in the mean difference between two large data sets can be estimated rather simply with a "two-sample t-test", if the data sets are normal distributed. If the data sets are not distributed normally, estimating the uncertainty in the mean difference can be very difficult at best. Since the process and cost parameter uncertainties are not all normally distributed, and the process model is not necessarily linear, it should not be expected that the remediation cost and HLW glass volume outcomes be perfectly normally distributed. However, as shown by Figures 9 and 10, an approximation of normal distribution is not unreasonable.

Figure 13 represents the difference between the nonESW and ESW mean value TWRS remediation costs. The distribution reflects the uncertainty between mean values as estimated by the "two sample t-test". The distribution is normal with a mean value equal to the difference between the nonESW and ESW mean value TWRS remediation costs, and a standard deviation previously defined by Equation 1. The "two sample t-test" is often used in medical research to determine whether or not two unique populations truly respond differently to treatments.

This study has indicated that within the accuracy of the assumptions its methodology is based upon, use of ESW at Hanford will save $4.8 B ± $1.6 B at the 95% confidence interval. The 95% confidence interval is generally used by statisticians to reflect a reasonable uncertainty, such that the estimate would be correct 95 out of 100 cases. Often this type of analysis is too involved for a particular application and uncertainties are reported as simply a range. An example of this was the HLW glass volume estimated by the "Independent Review of Hanford HLW Volume" team, to be 13,800 to 50,000 canisters with a median value of 23,000. This study took their estimate and applied the triangular distribution of Figure 7. The affect of this is to actually reduce confidence intervals because the probability of occurrence is superimposed on the range. Therefore, while $1.6 B may seem like a small uncertainty for the $4.8 B cost savings given the overall remediation cost uncertainty, it would actually be much larger if a higher than 95% confidence interval (albeit unreasonable) is applied.

As noted earlier, the ESW $4.8 B cost savings has already been included in the Hanford site remediation cost baseline. The ESW savings estimated by this study is due to the ~$30M DOE has invested in the related technology development. It demonstrates an extremely favorable rate of return on investment as estimated in an earlier study [DeMuth and Shieh, 1999].

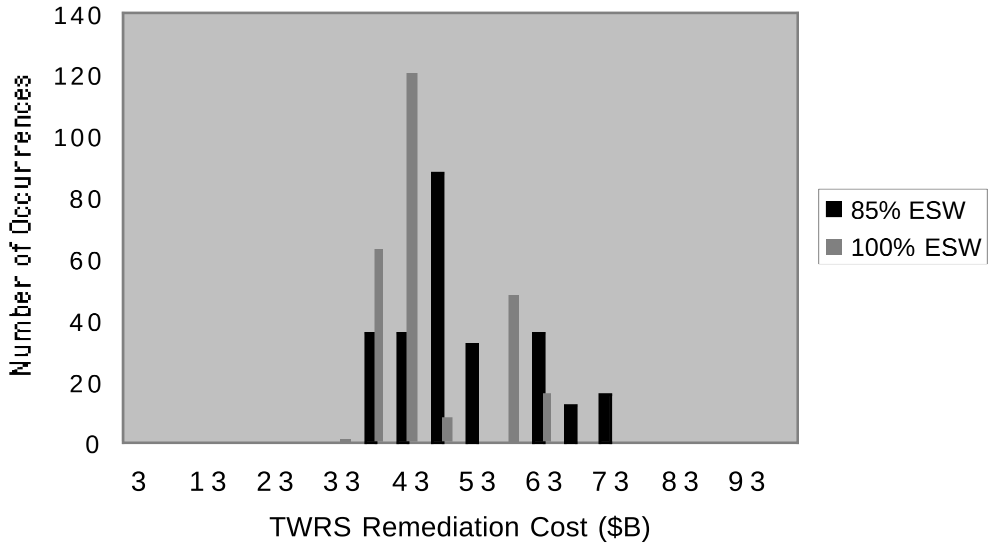

Figure 9. Discrete Remediation Cost Outcomes

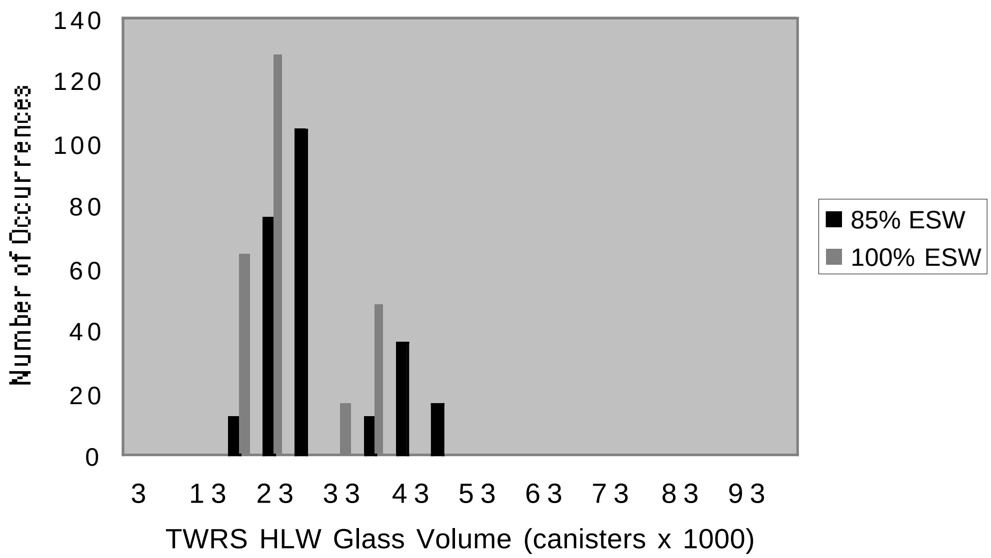

Figure 10. Discrete HLW Glass Volume Outcomes

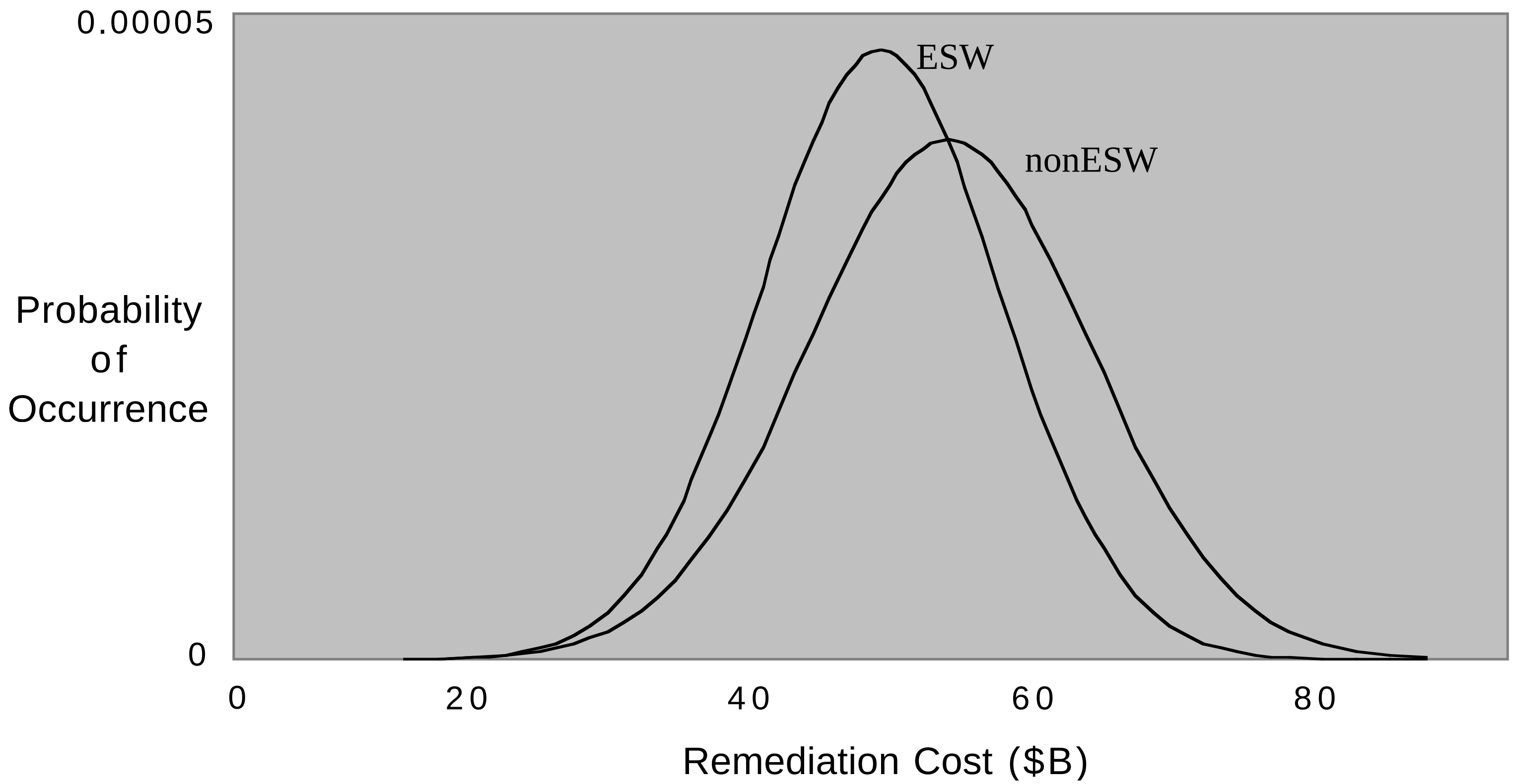

Figure 11. Continuous Distribution for Remediation Cost Outcomes

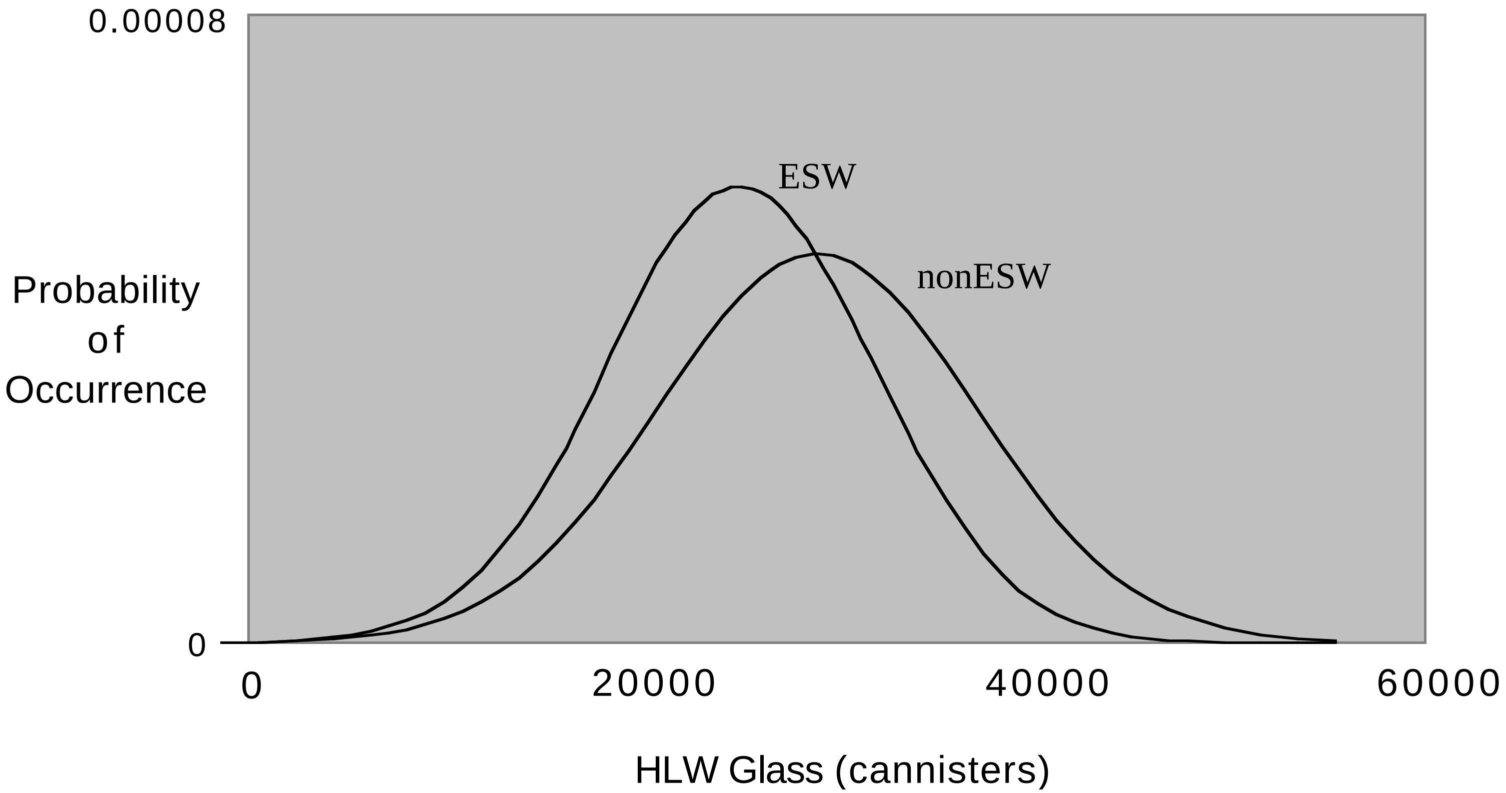

Figure 12. Continuous Distribution for HLW Glass Volume Outcomes

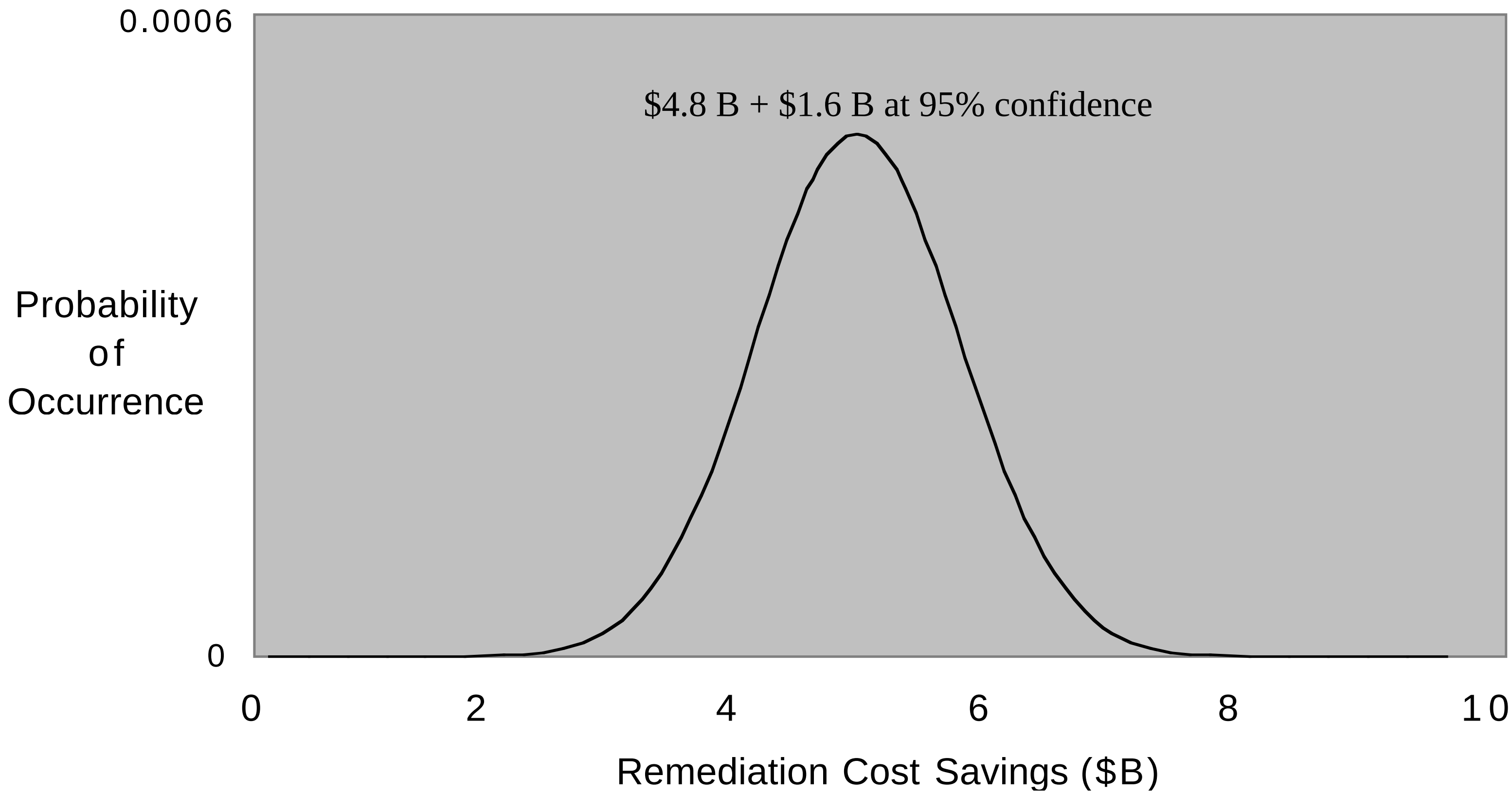

Figure 13. ESW Cost Savings with Uncertainty

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